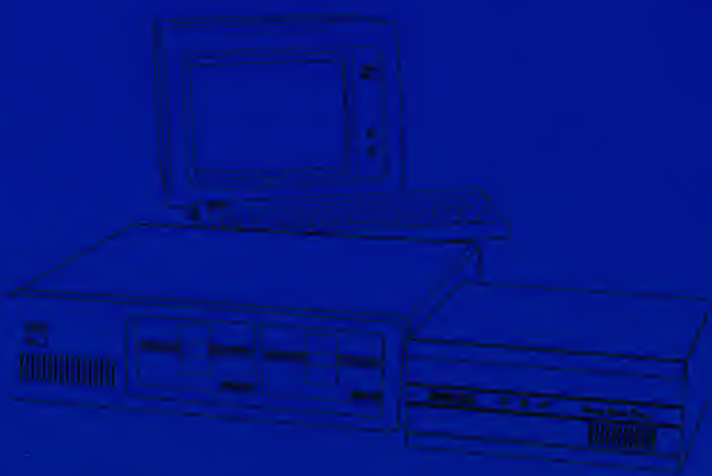
Inside Personal Computer Disk Storage Systems



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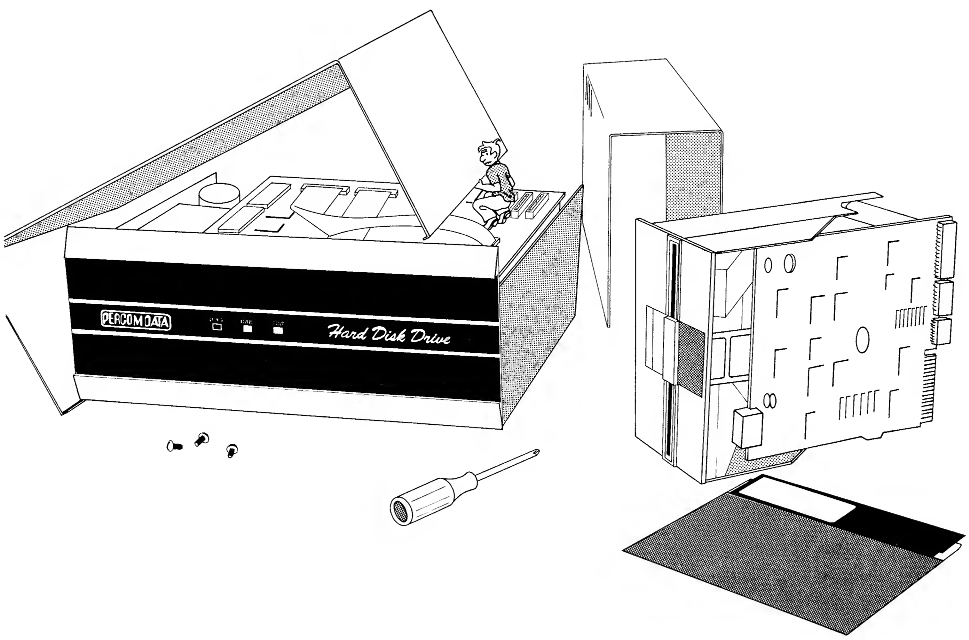
Preface

This is a small book about a big part of personal computing: information storage and retrieval. It's a book written for people who own personal computers, and for people who will become owners. It's a book for the microcomputer buff, and for the individual to whom the computer is not an end in itself.

Because most personal computers use magnetic disks for information storage, the text, of necessity, is about these disks. But, more importantly, it's about the hardware and software required to make them work. Section 1 introduces the subject. The disks themselves are described in Section 2. Sections 3, 4 and 5 get into the drives, the computer interface and the software. In Section 6, we briefly mention Percom Data's contributions to personal computer information storage. Beyond that, this little book makes no attempt to sell you on any product or any company.

Driving a fine automobile is nice, but real appreciation requires some reading and a peek under the hood. This booklet, "Inside Personal Computer Disk Storage Systems," gives you a "peek under the hood" of what is arguably your most important computer peripheral.



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Introduction 1

Computers process information, and magnetic disk storage systems give your computer a way to quickly and efficiently store and retrieve this information. In business applications, disk storage systems take the place of filing cabinets. With proper care and handling, a disk file is just as permanent as a manila file in a steel cabinet.

A magnetic storage disk is a thin platter coated on both surfaces with ferric oxide, a magnetic compound. Almost all personal computers use disk drives made for 5¼″ disks, and these 5¼″ drive systems and their diskette storage media are the focus of this booklet.

Units of information — numerals, letters, punctuation marks and other alphanumeric characters — are magnetically recorded on the disk surface in narrow concentric rings called tracks. Information is "read" from a track or "written" on a track by spinning the track under a read-write head. An audio cassette works similarly, except it is said that the audio is "played" instead of "read," and "recorded" instead of "written."

There are two main types of personal computer disk drives: floppy disk drives, which use removable plastic disks, and Winchester disk drives, which use non-removable metal disks. Winchester drives also are called hard disk drives or rigid disk drives. Hard disk drives provide an advantage in speed, storage capacity and reliability over floppies, but the entry price is higher.

A personal computer disk storage system is a complex union of hardware and software no easier to understand than the computer itself. Besides the media, i.e., the disks, a basic system consists of a disk drive unit, a disk drive controller, and operating software. The drive unit is an electro-mechanical assembly. It spins the disk and positions the read-write head over the recording tracks. The disk drive controller, or simply, "controller," provides a compatible physical-electrical interface between the computer and the disk system. The disk-operating software controls positioning of the read-write head, and manages the information flow between the computer and the storage unit.

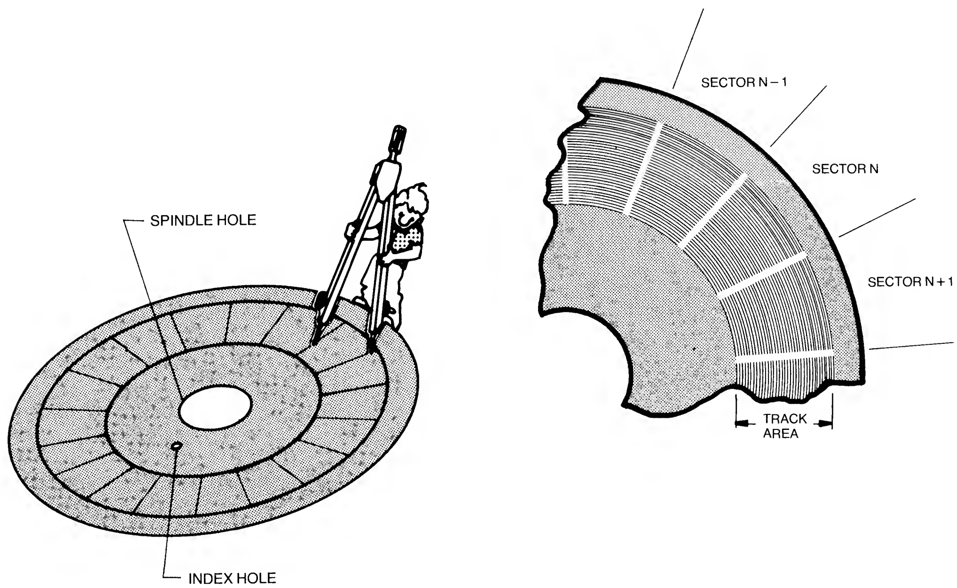
Some computers accommodate disk drive units as integral components, while other makes are designed for the drive units to be separate modules. Although the drive unit is the center piece of a disk storage system, the design of the controller and the sophistication of the software are, if anything, even more important to the quality of disk storage operation.

Disk drive units have their own ac-to-dc power converters, and a well-designed, cool-running power supply is essential to dependable disk system operation. Disk drive power supplies, however, are like those used in many types of electronic devices and therefore are not reviewed here. Otherwise, this little book is a full overview of the basics of personal computer disk storage systems.

Being an introductory treatment, we've tried to avoid the jargon of computerists. But in a small book, this is impossible. So where we couldn't, we've defined terms and expressions, using apposition and short definitions, as we went along. The index can be used to locate these definitions for later reference.

Disks: The media for the message 2

Information storage disks used by computers are made in different sizes and types. Whether large or small, floppy or rigid, the method of information storage is fundamentally magnetic, that is, characters are stored by arranging microscopic "magnets" into patterns, with a different pattern representing each character. Information — strings of characters — is stored on the surface of a disk in narrow concentric circular tracks that are divided into equal-size arcs. In computer terminology, the arcs are called sectors.



Data Storage Disk — Information is stored on a magnetic surface coating in narrow, circular data tracks. Tracks are divided into equal-size arcs, which are called sectors, and are numbered from the outermost track inward. The first track is numbered 0 or 00. The last track of a 40-track drive, e.g., is track number 39. The index hole marks the start of all tracks.

Fast data access

Magnetic disk storage systems provide computers with the ability to record and retrieve information randomly. This is like being able to go straight to your post office box without first inspecting box #1, box #2, box #3, etc. Similarly, a drive system read-write head can scoot right to the place of storage on a disk without examining sequentially all recorded data. Random access capability is indispensable for most business applications.

Floppy disks

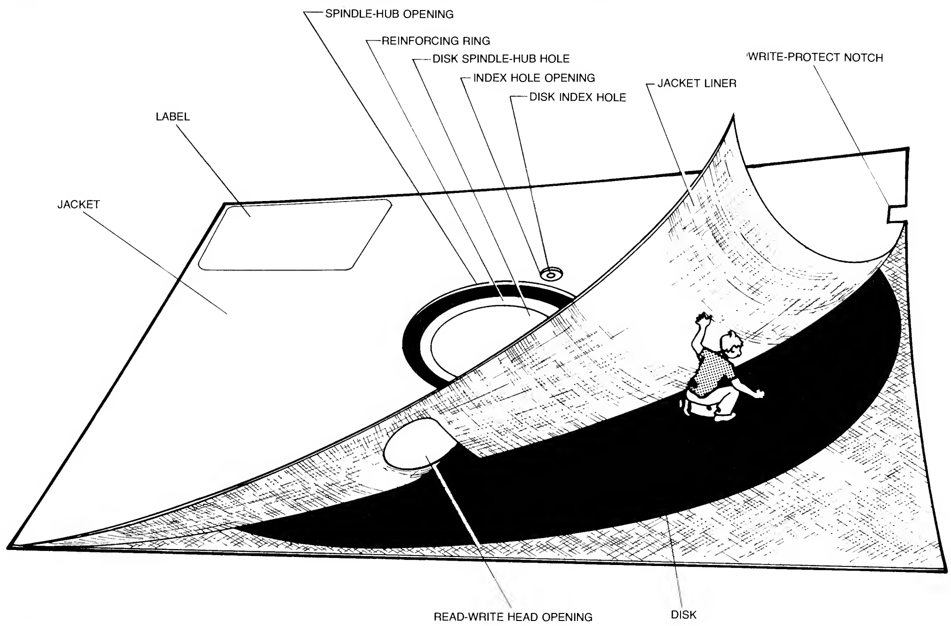
Floppy disk technology was developed by IBM in the mid 1960's. A floppy disk is a paper-thin polyester platter, either 5¼″ or 8″ in diameter (approximately) with a coating of magnetic oxide on both surfaces. Personal computer owners call the smaller size disks diskettes, as we will when it is important to distinguish between the two sizes.

Although both surfaces of a disk have magnetic coatings, for some brands of flexible media only one surface is certified for data storage by the manufacturer. Drives that access both surfaces of a disk, "flippy" and two-head drives, should use disks that are certified for two-sided storage. Also, some disk manufacturers still classify their media for either single- or double-density storage. The subjects of flippy and two-head drives and storage density are discussed in later Sections.

An 8″ floppy disk can store more information than a 5¼″ diskette. But 8″ floppy disk systems cost more, and primarily for this reason, most personal computer floppy disk systems are built for diskettes. Also, as floppy technology evolved, engineers were able to pack more information on disks. Today, the equivalent of about 45 typed pages — 150,000 characters or so — can be stored on one surface of a 40-track, 5¼″, double-density diskette, the most popular format for personal computer applications.

Reliability

Like magnetic tape, the floppy disk recording surface must be kept dust free and unmarred, and therefore floppy disks are sealed in a polyvinyl chloride jacket. The inside surfaces of the jacket have soft liners that wipe the disk clean as it spins. A disk is inserted, jacket and all, in a drive. In fact, a disk should never be removed from its protective jacket. Disk manufacturers call the jacketed disks cartridges.



Diskette Reliability — Disk surfaces are polished, burnished and lubricated to resist abrasive head-disk wear. The jacket liners clean and remove debris from the disk surfaces while the disk spins. The reinforcing hub ring reduces wear of the spindle opening, and provides better long-run head-to-track alignment repeatability.

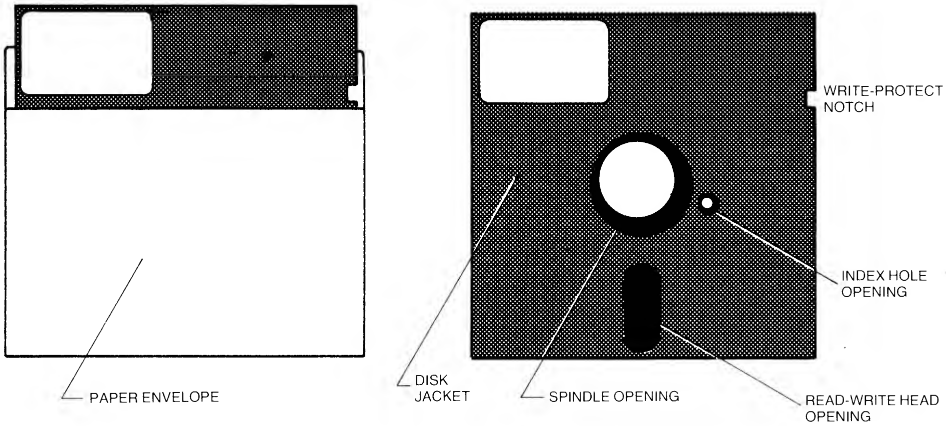
The useful life of a floppy disk is rated by disk manufacturers in terms of the number of passes a read-write head can make over a track before a wear defect might occur. Since the media surfaces and the drive read-write heads are polished to microscopic smoothness, a rating is typically several million passes. It's hard to estimate the average lifetime of a disk, but with reasonable care and proper handling you should expect years of use before a head wear spot causes data errors.

Diskettes, if used and stored properly, will preserve recorded information practically forever. The do's and don'ts of caring for floppy disks are found in disk system users manuals, printed on the back of disk containers and elsewhere in the literature, and won't be repeated here except for one caveat: be careful about exposing disks to a magnetic field. One sadder-but-wiser computerist reported storing media near floor level where the powerful magnetic field of a floor-cleaning machine erased many man-months of recorded information.

The disk protective jacket, which is square and relatively stiff, has three openings. The large hole in the center is for the disk drive hub or spindle. Most floppy disk vendors now offer disks with plastic reinforcing hub-spindle rings. These resist wear that can cause head-to-track misalignment and unreliable storage operation. Head-to-track alignment is more critical on high-density 80-track drives. The elongated opening is for the read-write head, which contacts the disk during read-write operations. This opening spans a little more than the width of the track zone. The third opening, a small round hole, lets the drive mechanism detect reference holes punched in the disk.

Hard- vs. soft-sectoring

Every disk has at least one reference hole, or index hole, to mark the beginning of tracks. Some disks have holes to mark every sector, the sector holes lying equally spaced on a circle a little bigger than the hub opening. Disks with sector holes are said to be hard sectored, meaning that the physical sector length is immutably fixed. Disks with only a start-of-track index hole and no sector holes are said to be soft sectored. The sectors of a soft-sectored disk are identified by addresses magnetically recorded at the beginning of each sector, and soft

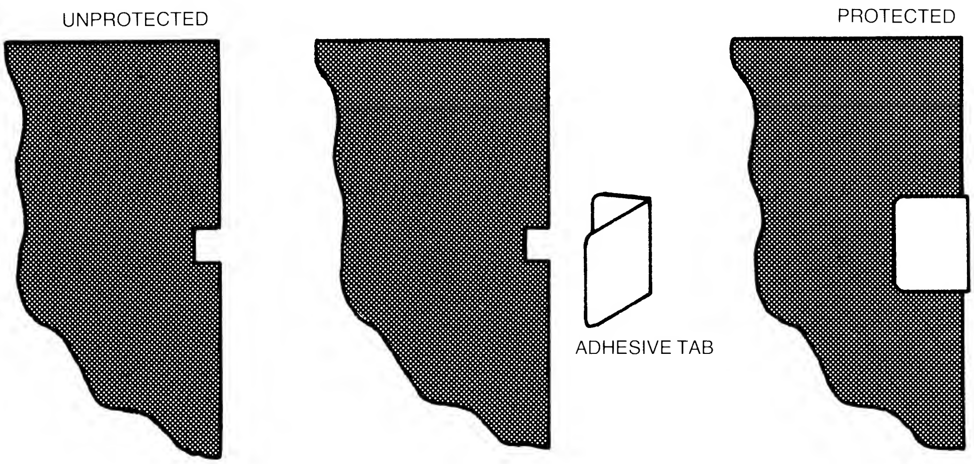


Jacketed Diskette — A floppy disk should never be removed from its polyvinyl chloride jacket; openings in the jacket provide for access by the disk drive unit. The location of the write-protect notch indicates that this is a 5¼″ diskette, and not an 8″ floppy disk, which has the write-protect notch in the bottom edge. The disk itself can be seen through the jacket openings.

sectoring, thus being amenable to software-controlled formatting, is not immutable. The ID marking takes up a little space on each sector, so soft sectoring is not quite as space-efficient as hard sectoring. Nevertheless, proponents of hard sectoring early on lost the battle to advocates of soft sectoring, and today all of the most popular microcomputer disk storage systems use soft sectoring. Soft-sectored and hard-sectored disks are not interchangeable, although, with special software, soft-sectored disks can be read on hard-sectored drives.

Accident insurance

The notch in the edge of the floppy disk jacket provides a sure way to prevent recording (writing) on a disk. This is important because newly written information replaces previously stored information, and the old information is irretrievably lost. Diskettes — 5¼″ disks — are protected against this happening by covering the notch with an opaque write-protect tab, a small adhesive-backed label. Eight-inch disks are write-protected if the notch is left uncovered. Floppy disk drives have sensors that detect the disk holes and jacket notches, and signal when a hole is over the sensor or if the write-protect notch is uncovered.



Write Protection — Information cannot be written (recorded) on a 5¼″ diskette if its write-protect notch is covered. An 8″ floppy disk, by contrast, is write-protected when the notch is uncovered. The adhesive write-protect tabs used on diskettes must be opaque, and the ones supplied by disk manufacturers usually have a reflective coating on the outside.

Winchester disks

The disks used in Winchester drives for microcomputers also are either 5¼″ or 8″ in diameter. Actually, neither Winchester nor floppy disks are exactly 5¼″ or 8″ across, but they're close and are referred to as 5¼″ or 8″ disks. The smaller 5¼″ disk drives are used with personal computers. Winchester disks are not removable and users needn't be concerned with manual write-protection and the different types of sectoring. The main physical difference between floppy and Winchester disks, also of no practical concern to most users, is flexibility: Winchester disks have metal substrates and are rigid; floppy disks have polyester substrates and are flexible.

Although rigid disks are no bigger than floppies, they store a lot more information, a point underscored by the fact that the storage capacity of rigid disk systems is specified in terms of millions of characters — in megabytes or Mbytes — while the storage capacity of floppy disk systems is specified in thousands of characters or Kbytes. (In microcomputing, K (upper case) stands for 1,024 and the traditional engineering k (lower case) stands for 1,000). The higher capacity of Winchester drives is essentially the result of a smaller-dimension, greater-precision technology than that used in the design and manufacture of floppy disk drives.

Incidentally, "Winchester" is the name of the technology, not the name of an inventor or a computer company. The first drive to incorporate Winchester technology, an IBM product, stored 30 megabytes on each disk surface, and informal reference to the unit as the "30-30" evolved into "Winchester," after the name of the manufacturer of the famous Winchester 30-30 rifle. The differences between Winchester and floppy disk drives are examined in more detail in Section III.

On-line vs. off-line storage

Since floppy disks are removable, floppy disk storage systems provide unlimited storage capacity — which brings up a point to consider before purchasing a disk system. A disk in a drive that is connected to a computer is said to be "on line," that is, the disk is directly and immediately accessible to the computer. A disk stored in a plastic case on a shelf of course is not on-line. Although a floppy system provides infinite storage capacity, its on-line capacity, alas, is definitely limited. An important difference between floppy and Winchester storage systems is on-line storage capacity: a single Winchester drive, even a 5¼″ "minnie Winnie," provides more on-line storage capacity than a state-of-the-art multi-drive floppy system.

Hardware: The disk drives 3

Unless you're a computer engineer or system programmer, a disk drive is no less inscrutable than the host computer itself. Nor is a table of drive characteristics and specifications much help. So we'll attempt, in this Section, to describe disk drives in a way that doesn't require a doctorate in computer science to understand.

The basics

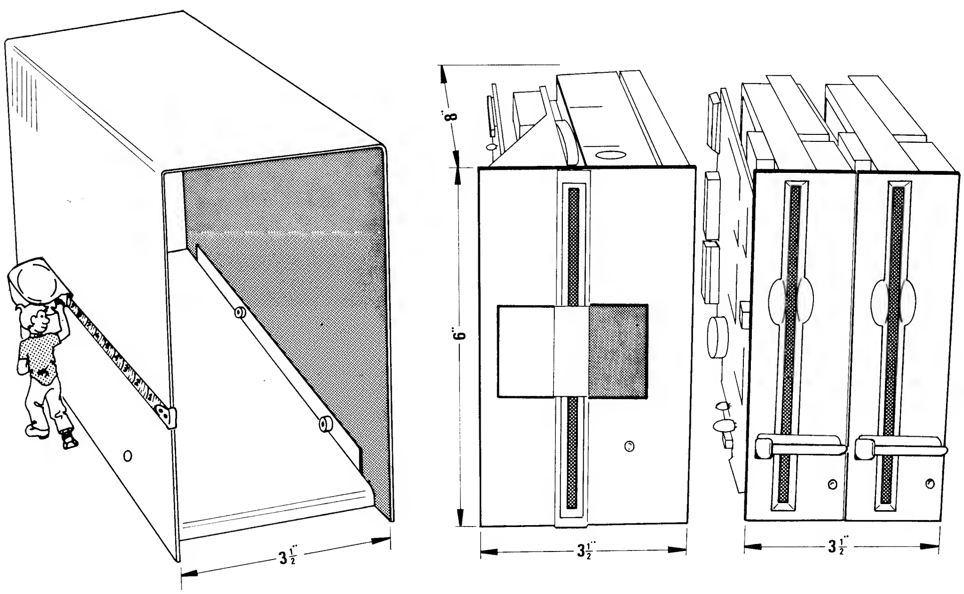
A disk drive is like a phonograph to the extent that information is read from a platter-shaped medium which revolves under a pickup device. Of course a phonograph only plays (reads) media, and its information tracks are spiral bumpy grooves instead of circular magnetic tracks. Stripped to essentials, a disk drive spins a disk and positions a read-write head on a track of the disk. Motors are used to spin the disk and "step" the read-write head into position. The motor that spins the disk — that turns the disk spindle — must run at constant speed. This ensures the reliable transfer of information between the read-write head and disk. The motor that positions the read-write head is a special type called a "stepper" motor. More on it later.

A disk drive assembly also includes a printed circuit board (PCB) for control of disk motor speed; for generating and manipulating read-write head control signals; for sensing index holes and a write-protect notch; and for processing the data signals themselves. The disk motor speed control circuit is often implemented on a second circuit board.

Floppy disk drives

Floppy disk drives come in sizes compatible with the two popular floppy disk sizes, and are referred to as 5¼″ (or 5″) drives and 8″ drives. Almost all personal computers use the smaller drives, which are available in 40- and 80- track versions with either one or two read-write heads. The storage capacity of a dual-head, 80-track drive is nominally four times that of a single-head, 40-track drive — as would be expected. Eight-inch floppy drives are made with either single or dual read-write heads, for a 77-track disk format.

The dimensions of a standard unenclosed 5″ drive, without a power supply, are about 8″ by 6″ by 3½″. In 1982 several drive manufacturers introduced a "half-height" floppy drive that is about 8″ by 6″ by 1¾″ — slim enough that two such drives can fit in the same space as one regular 5″ drive.

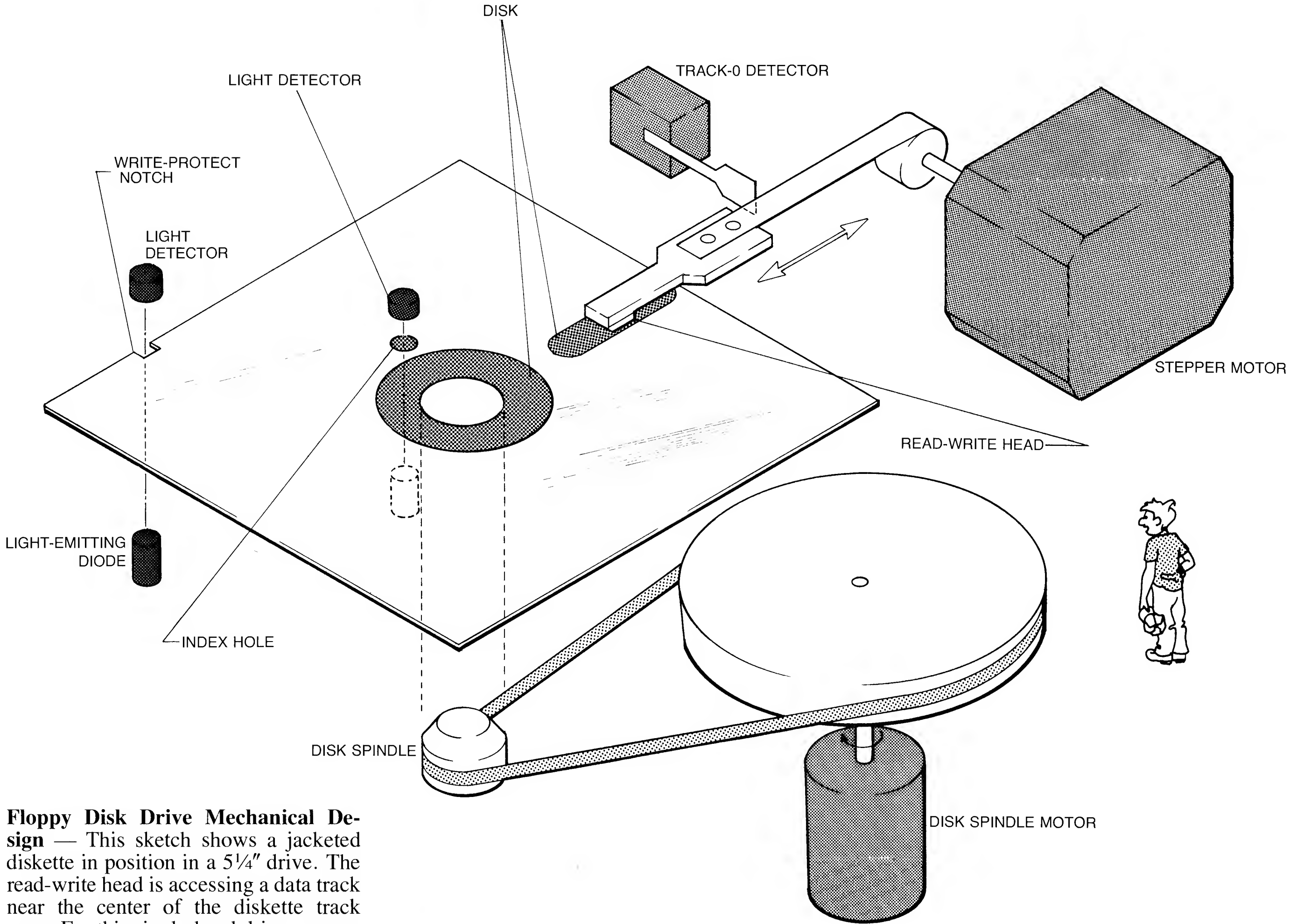


Full-Height and Half-Height 5¼″ Floppy Drives — Two half-height drives fit in the same enclosure as a single full-height drive. The slim, newer drives use the same diskettes as the older design.

Also, Sony in 1981 introduced a 3½″ "microfloppy," and other suppliers have indicated their intention to follow suit. Whether or not microfloppies replace 5″ floppies as the standard personal computer disk storage unit remains to be seen.

The flip side

Before getting into the details of floppy drive design and operation, one more type of 5″ floppy needs to be mentioned. This is the "flippy" floppy, a one-head floppy drive with two sets of index-hole and write-protect sensors. The second set of sensors allows a user to flip a disk and store information on the "back" surface. Flippy drives do not increase *on-line* storage capacity, but they do save on the cost of diskettes, which run about $4.00 to $6.00 each. Also, be aware that flippy operation may be somewhat unreliable because reversal of the direction of disk rotation, which happens when the disk is inserted top side down, releases dust collected by the disk jacket liners.



Floppy Disk Drive Mechanical Design — This sketch shows a jacketed diskette in position in a 5¼″ drive. The read-write head is accessing a data track near the center of the diskette track zone. For this single-head drive, a pressure pad under the diskette is loading the read-write head. The mechanically actuated track-0 detector signals the computer when the head is over the outermost track. Some drives use an electronic detector for this function. If the write-protect notch was covered, the LED output would be blocked, causing the light-detector circuit to send a write-data disabling signal. The diskette spins continuously before, during and for a few seconds after a data access operation.

Rotating the disk

The disk must be rotating at constant speed during disk-head information transfers to ensure the integrity of the data. Most 8″ floppy drives use ac motors that synchronize with 60-cycle (60-Hz) line power to rotate the disk at six times the line frequency, or 360 rpm. Five-inch floppy drives use dc motors with constant speed control circuitry, and are designed for a disk speed of 300 rpm. Because of their higher rotational speed and greater diameter, the rate that information is read or written is higher for an 8″ drive than for a 5″ drive. Data transfer rate is an important parameter and will come up again.

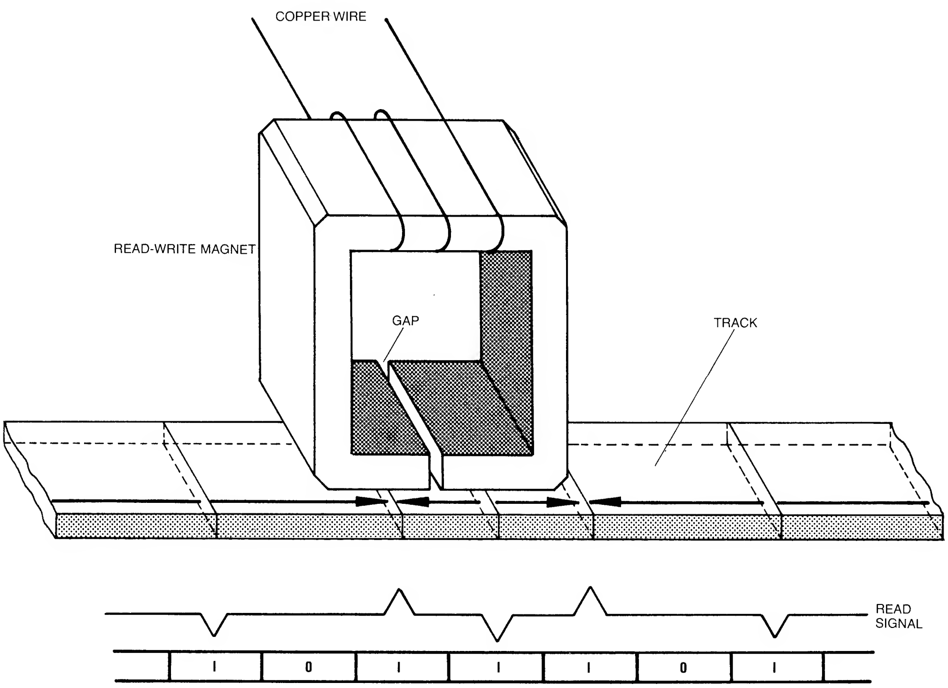
For an 8″ drive, the spindle motor usually runs all the time — as long as power is applied. For a 5″ drive, however, the spindle motor does not run unless commanded to do so by the computer. Furthermore, the motor of a 5″ drive "times out" and automatically stops running a few seconds after a disk-accessing operation. This feature extends the life of the spindle motor. An LED (light-

emitting diode) on the front of the drive indicates when the spindle motor is running — the light coming on at the start of an access operation and going out several seconds after the operation ends. An operator regains system control, and can resume using the computer as soon as the ready prompt appears on the computer screen even though the indicator lamp is still on and the disk motor is still running.

A disk is inserted or "loaded" into a drive by slipping the jacketed disk into a slot at the front of the drive and closing the drive door. The door will not close unless the disk is inserted all the way. The read-write head access slot on the jacket goes in first. When the door of the drive is closed, the drive spindle-hub mechanism engages the disk.

The R-W head

The read-write head contacts the disk through an elongated slot in the disk protective jacket. The slotted opening provides access to all tracks.



Read-Write Head — The main element of a disk drive read-write head is a magnet formed of several turns of copper wire on a ring of ferrite. The ferrite core, which is about the size of a watch stem, has a hairline gap along the side that contacts the data track. When a current is passed through the coil, as happens during the writing of data, the disk surface under the gap is magnetized. The direction of magnetization — N to S or S to N — depends on the polarity of the write current. Changing the polarity instantaneously, as the disk spins, stores a '1' bit (binary digit), and not changing the polarity stores a '0' bit. In the read mode, a pulse of current is generated each time a polarity transition crosses under the head. The resulting pulses represent stored '1' bits. The absence of pulses, on the other hand, represent stored '0' bits. Besides the main magnet, a floppy disk drive read-write head includes two additional magnets that straddle the data track and "erase" the intertrack zones. This isolates tracks from each other.

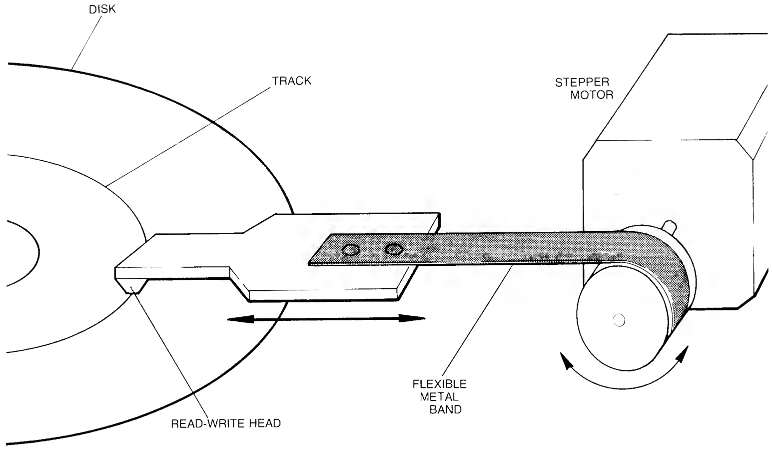
A pressure pad, which is directly opposite the read-write head and tracks the head movement, pushes against the back side of the disk to maintain head-to-disk contact. A solenoid, a magnet that can be turned on or off electrically, pulls the pressure pad against the disk. A control signal issued by the computer activates the solenoid. For two-headed drives, the inactive head serves as a pressure pad. The read-write head is said to be "loaded" when it is in contact with the disk. A finite time is required to load the disk, and this head-load time — about 5 hundredths of a second — generally must be taken into account in writing drive-operating software.

While the head is in contact with the spinning disk there is wear, although slight, and therefore head life is rated by drive manufacturers. A typical rating is 20,000 hours of actual access time. A large data base or a long program can be saved (or loaded) in 10 seconds or so, so you can expect to access a drive millions of times before the head wears to the point of causing data errors.

One step at a time

The drive read-write head is mounted on a carriage that slides on rails to provide access to all disk tracks. A special motor called a stepper motor is mechanically linked to the head carriage in such a way that rotary motion of the motor shaft is transformed into linear (in and out) motion of the head carriage.

Head-Positioning Mechanism — The flexible metal band transforms rotary motion of the stepper motor into the linear motion required to position the read-write head. Other mechanisms, including rack and pinion, spiral cam and lead screw, are used for the linear-to-rotary translation.



A stepper motor rotates through a fixed, small angle in response to a pulse of electrical energy, so that very precise positioning of the head may be accomplished by pulsing the motor a predetermined number of times to reach a track. Some makes of 8″ floppy drives (and some rigid-disk drives) use other ways to position the read-write head, but stepper motors are used in 5″ floppy drives.

An important characteristic of floppy drives is the time it takes to move the head from one track to an adjacent track. This is called track-to-track step time, and it ranges from 5 milliseconds (.005 second) to as much as 40 milliseconds, depending on the make and model of drive. Drives with slow step times will not work with some personal computer systems.

Seek time is another parameter of head positioning. A "seek" operation generally involves stepping across several tracks to reach a particular track — sometimes after first homing to track zero for positional reference. Head settling time, the time it takes for the read-write head to stop vibrating at the finish of a seek operation, also figures in the total time required to access information, as does head load time. Average access time — the combination of seek, load and settling times — ranges from about 1/5 to 1/3 second for 40-track, 5″ drives.

Reading the right signals

A 5″ floppy disk drive typically includes two printed circuit boards. One board — usually referred to as the servo board — contains the disk motor speed control circuit. The other board contains the data, control signal and power interfacing electronics. The speed control and power interfacing electronics are neither unique nor especially interesting. Data and control signal interfacing, however, involve points of interest about applications that need to be examined.

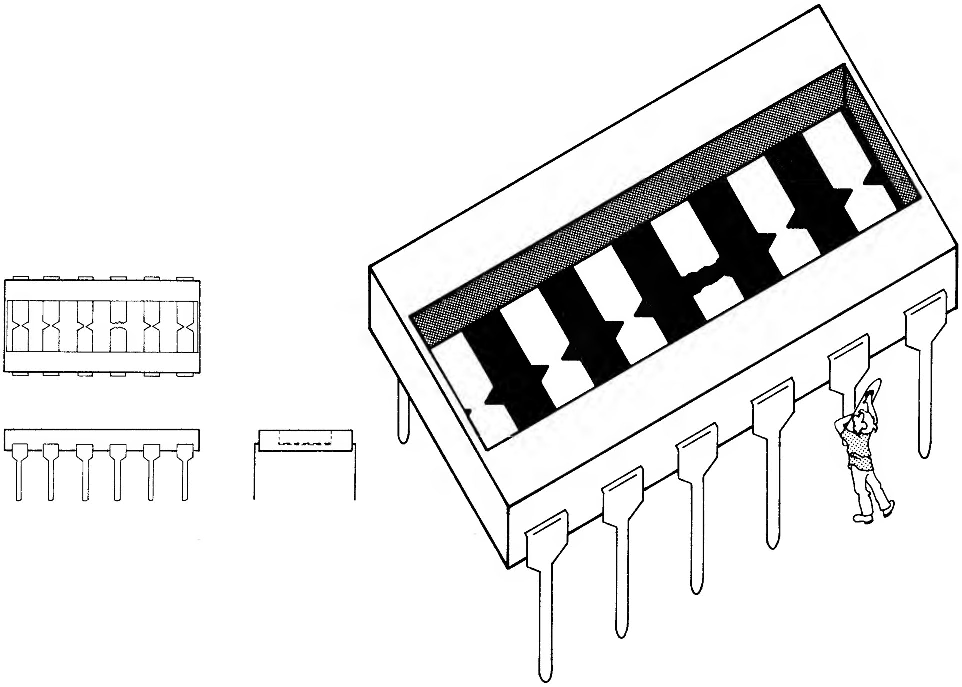
Disk drive signals may be classified as either information signals or control signals. There are two information lines: one conductor, called the write-data line, carries information from the computer to the drive, and one conductor, called the read-data line, carries information from the drive to the computer.

Disk drive control signals also are either input or output signals. Input signals originate at the computer (or drive controller) and output signals originate at the disk drive. Input control typically provides for drive selection — most systems have more than one drive — spindle motor on/off control; head selection, positioning and loading; and a line for a write-enabling signal. Output control signals, that is, signals that originate at the drive, inform the computer about disk write-protect status, the position of the read-write head and where the tracks begin.

Drive IDs

More than one disk drive can be used with personal computers. In fact, many personal computer disk drive controllers will handle up to four drives. In multidrive systems, each drive must be uniquely identifiable to the computer's software. This is accomplished either by "programming" the drive, or by wiring only one drive select line per drive connector on the drive interconnecting cable.

The drive printed circuit board includes a plug-in jumpering block that looks like an integrated circuit (IC) with the lid removed. This part, usually referred to as a "shunt" in user manuals, provides for programming a drive as drive #1, drive #2, etc. (or drive #0, drive #1, etc.). The "programming" amounts to severing one or more of the frangible conductor links of the IC shunt.



Programming Shunt — In a multi-drive system, each drive must be set up with its own access ID number. This is done with a programming shunt, like the one shown, or in the wiring of the drive cable connector. A programming shunt plugs into an IC socket on the drive electronics PC board. One is included with each drive. A drive's ID number depends on the number of shunt contacts which are left intact. In this diagram, only one has been broken. Instead of severing the contacts, some computerists merely pull the device pins out of their socket contacts. When the drive system manufacturer sets up drive access numbers in the cabling, the programming shunt should remain installed and left unchanged from the way it was shipped.

Drive numbering by differently wiring each cable drive connector merely involves attaching only one drive-select line (conductor) per connector. In other words, only the drive-1 select line is wired to the connector at cable position 1, only the drive-2 select line is wired to the connector at position 2, etc. When manufacturers provide selectively wired drive cables, the user doesn't have to set up the programming shunt of each drive.

No surprise endings

As explained, disk drives are connected to a computer with a cable that has positions (connectors) for several drives. One drive connects to the end of the cable, and that drive must include a cable terminating load. This load is an IC resistor network that plugs into a 14- or 16-pin socket on the drive printed circuit board. When electronic signals arrive at the end of an unterminated cable they bounce back toward their source, mixing with the original signals in a way that can cause faulty operation. An unterminated cable can be an especially insidious source of malfunctions because failure symptoms are inconsistent and irregular. In a multi-drive system, the drive at the end of the cable, and only that drive, should have a terminating load.

Winchester drives

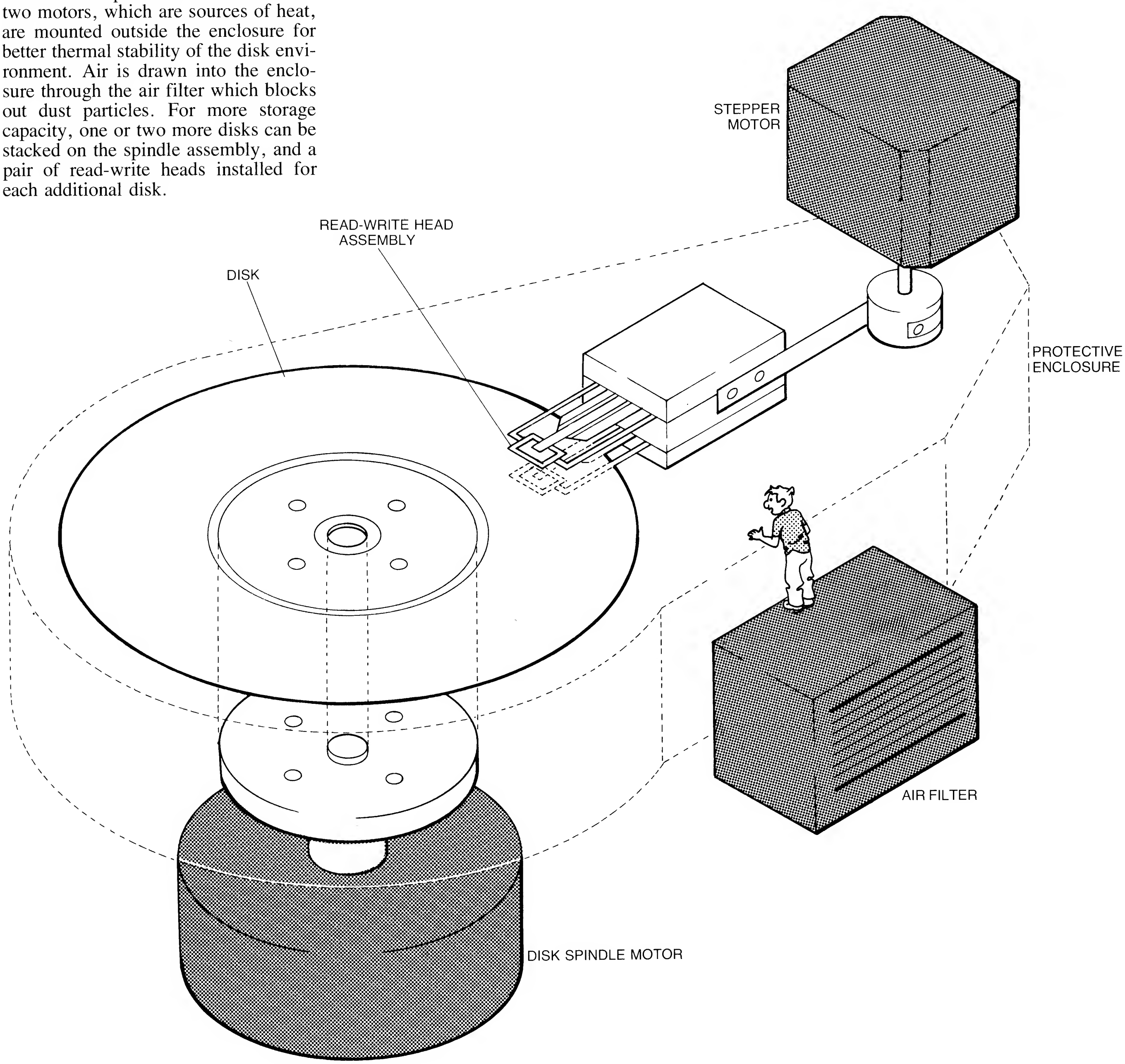
A floppy disk drive stands in about the same relation to a rigid disk drive as a small private airplane stands in relation to a multi-engine corporate jet. In each case, the engineered differences are enormous even though the underlying principles are basically the same.

Without increasing the size of the medium — the area of the recording surface — the way to increase disk storage capacity is to increase the character storage density, that is, to pack the characters most closely together. And the way to increase the data rate, the rate that information is written to or read from a disk, is to get characters passing the read-write head faster. Winchester technology, which resulted as engineers pursued these goals, defines a type of disk drive that is being used more and more with personal computers.

There are several characteristics of Winchester disk drives that make them different from floppy drives:

- The disks and read-write heads are sealed in a protective chamber, called the head-disk assembly, and are inaccessible to the computer operator.
- The read-write heads are smaller and lighter than floppy disk drive heads, and have an aerodynamic profile.
- The read-write heads do not contact the disks, except when the drive is stopped, but instead take off and fly low over the surface of the disk on a cushion of air created by the spinning disk.
- The disks of rigid disk drives rotate about 10 times as fast as floppy drive disks, ranging in speed from about 2400 to 3600 rpm.
- The head-disk data transfer rate of a 5″ Winchester is typically 625,000 characters per second, 20 times that of a double-density 5″ floppy.
- The disks are metal instead of plastic, that is, the substrates for the magnetic coatings are metal.
- The magnetic coatings on the disks, or platters as they are called by drive manufacturers, are thinner than for floppy disks. This permits higher character densities.

Rigid Disk Drive Mechanical Design — This one-disk Winchester drive has two read-write heads, one for each disk surface. Air movement generated by the spinning disk causes the aerodynamically shaped heads to "fly" 20-50 millionths of an inch off the disk surfaces. The disk, read-write head assembly and mechanical linkage to the stepper motor are inside the protective enclosure. The two motors, which are sources of heat, are mounted outside the enclosure for better thermal stability of the disk environment. Air is drawn into the enclosure through the air filter which blocks out dust particles. For more storage capacity, one or two more disks can be stacked on the spindle assembly, and a pair of read-write heads installed for each additional disk.

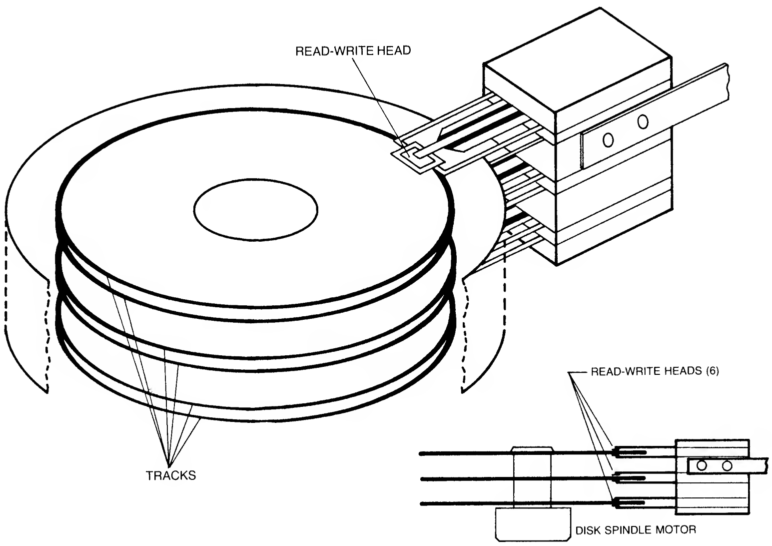


The dimensions of a 5″ Winchester drive assembly are the same as those of a 5″ floppy drive: 8″ by 6″ by 3½″. In late 1982 or early 1983, half-height 5″ Winchesters will be available from several manufacturers.

Although you can purchase rigid disk drives that plug into the same equipment slot as a floppy, unfortunately, it's not a simple swapping out exchange. This is because the floppy drive controller, the interface between the drives and the host computer, is different from a rigid disk controller in key respects. It would not be difficult to include both floppy- and rigid-disk drive capability in one universal controller, but this is not now generally done. Disk drive controllers are the subject of the next section.

Winchester R-W heads

Rigid disk drives always have opposing read-write heads for accessing each disk surface; in fact, some expensive, high throughput units have more than one pair of heads per disk. Moreover, the higher capacity drives have more than one disk — a 5-megabyte drive may have one disk, a 10-megabyte drive two disks and a 15-megabyte drive three disks. The disks are all mounted on the same spindle, and the heads all move in and out in unison. This multiple head, multiple disk arrangement gives rise to the concept of data cylinders, a cylinder being comprised of two to six data tracks (in this example), one above the other, on each of the two to six disk surfaces.

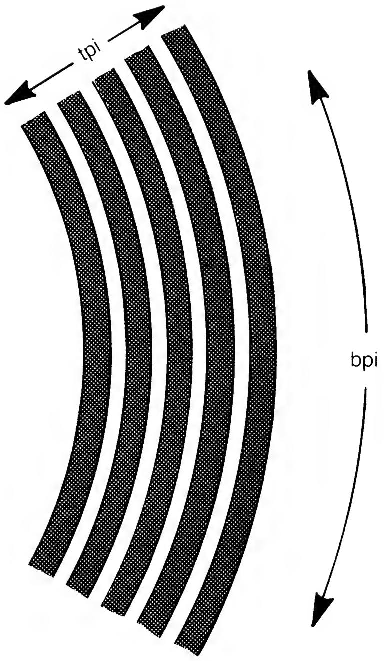


Data Cylinders — The disks of a multi-disk Winchester drive all turn on the same spindle. The read-write heads, a pair for each disk, are ganged and move in and out together. This allows sets of data tracks — six tracks per set for the three-disk drive of this illustration — to be thought of as data cylinders, and disk-operating software to be written so that each six-track cylinder can be accessed as one continuous track.

In late 1982, Winchester manufacturers were beginning to ship evaluation quantities of single-platter 5″ drives capable of storing as much (or more) information as three-platter drives. This advance is the result principally of new, smaller recording heads, which are made using the microfabrication techniques of integrated circuit manufacture.

Read-write heads of production 5″ Winchesters are small and precise enough to allow track densities of up to about 250-300 tracks per inch, compared to 48 and 96 tracks per inch for 40- and 80-track 5″ floppies. Of course squeezing the tracks more closely together imposes tighter tolerances on head positioning. One consequence of this track packing crunch is that manufacturers had to quit using plastic for the disk substrate, because of its relative thermal and hygroscopic instability, and use metal instead. Also, drive designers have, in some cases, resorted to means other than simple stepper motor actuation to ensure more precise positioning of the read-write head.

During operation,the aerodynamic Winchester read-write head flies over the disk on an air-bearing surface generated by the spinning disk. The flying height is measured in millionths of an inch, and for current model 5″ Winchesters, this flying height is about 20 to 50 microinches. One drive design engineer compared this incredible achievement to flying a Boeing 747 an inch above a choppy sea at Mach 4 speed. The lower the head flying height, the greater may be the disk character storage density.



Disk Storage Density — The amount of information stored per square inch of disk surface depends on track and bit densities. The track density of 40-track 5¼″ floppies is 48 tracks per inch (tpi). Early model 35-track 5¼″ floppies and current 8″ floppies also format 48 tracks per inch. Eighty-track 5¼″ floppy drives double the track density to 96 tpi. Winchester 5¼″ drives feature track densities of about 250-300 tracks per inch. Bit density depends on several factors including characteristics of the disk magnetic surface, read-write head gap length and spacing between the head and disk. Bit density along a track is not too different for floppies and Winchesters. Floppy densities range from about 5,000 to 6,000 bpi and Winchester densities range from about 6,000 to 8,000 bpi. Much higher storage densities have been achieved in the laboratory.

Rigid disk technology involves microscopic dimensions and, as a consequence, it becomes necessary to ensure that the head-disk environment is free of particulate matter. If a read-write head should encounter debris even as small as a smoke particle — which easily could be bigger than the distance separating the head and disk — while the disk is spinning at its usual 50 to 60 revolutions per second, the result is likely to be destructive. The buzz word for this type of disaster is "head crash." To prevent head crashes, both the disks and the heads of rigid disk drives are sealed in a protective enclosure. An air filtration system recirculates air in the enclosure and keeps the particle count lower by thousands than the particle count of typical office air.

The bottom line

The net result of Winchester technology is greater storage capacity, faster data transfer rate and higher data integrity. You can get at least 10 times the capacity of a 5″ floppy drive in a rigid disk drive having the same form and fit factors for about five times the cost of a floppy. Since rigid disk drives outperform floppy disk drives and cost less per character of storage capacity, a rigid disk drive is a better investment — if the initial cost isn't too big a load.

Handle with care

Rigid disk drives are not quite as rugged — if that's the right word — as floppy drives. And floppies, of course, should be handled like any other delicate instrument. According to one leading Winchester drive manufacturer, rough handling accounts for more damage to Winchesters than all other factors combined. Dropping a 5″ Winchester from even one inch onto a hard surface can cause head flexure and possible "head slap" damage to disk surfaces. Also, Winchester vendors warn against bumping a drive during spin-down, because during spin-down the heads slowly lose their buoyancy and can be easily crashed onto disk recording areas.

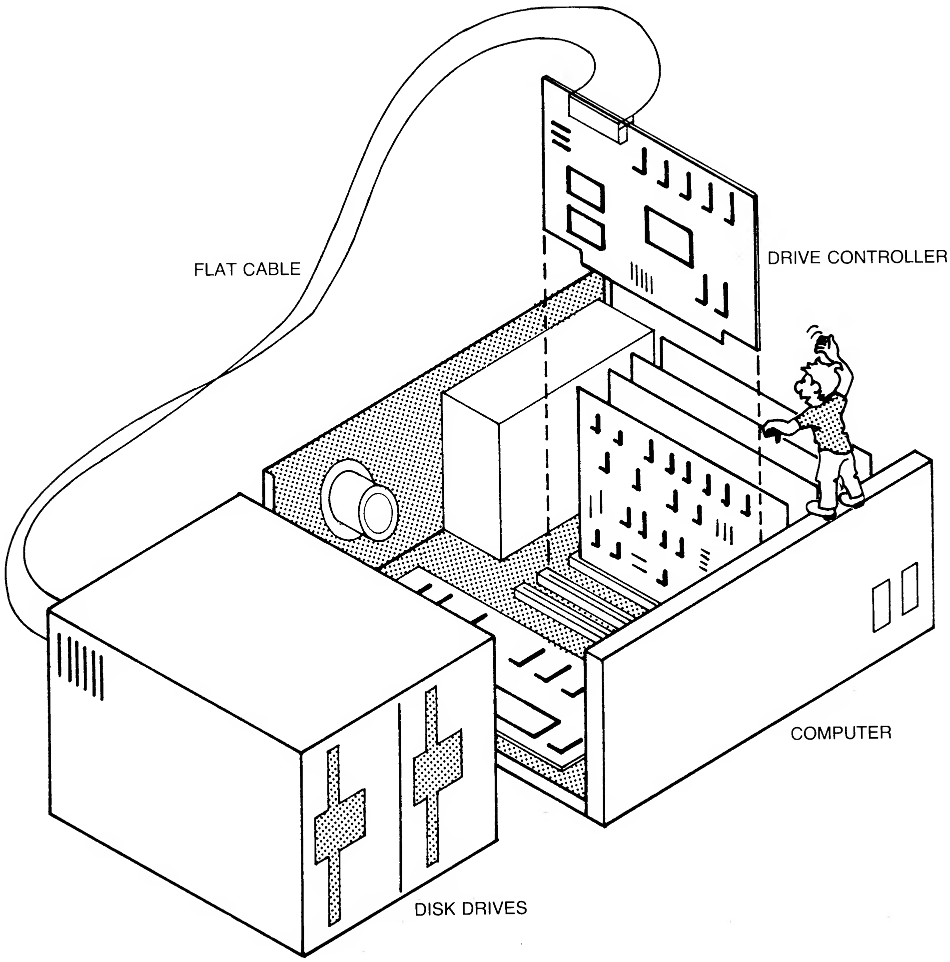
Backup

One last — but not least — consideration before purchasing a rigid disk storage system is a backup scheme. In most computer applications it is vitally important to maintain backup disks with copies of all disk-stored information — programs, record files, text manuscripts, etc. The reason, of course, is that all or part of the information on a disk can be irretrievably lost through operator error, equipment failure, an act of God or whatever. It is easy enough to backup floppy disks on a one-to-one basis, and most floppy disk operating systems include a utility program that provides for automatically — more or less — copying the entire contents of one disk on a backup disk. Backing up the information recorded on the disk of a rigid disk storage system differs from backing up floppy disks mainly in the volume of information that must be transferred. The massive amount of data involved, however, rules out the use of floppies for backup — except where the information base is small — and instead high-capacity, serial recording devices such as video and digital cassette recorders are used. These serial mass storage devices have ample capacity, backup a full disk in minutes and are less expensive than rigid disk storage systems. Because they are serial, however, these devices do not provide the high speed data accessing capability of disk storage systems.

The computer connection

4

Peripherals — disk storage systems, printers and other devices not usually a part of the computer "mainframe" — are connected to computers through adapter circuits. These adapters, which often are printed circuit board modules, reconcile physical-electrical incompatibilities, and sometimes, depending on the demands of the peripheral device, also provide complex signal processing and communications functions. The adapter circuit that sets up the channel of communication between a computer and a disk storage system is called a disk drive controller, or simply a controller.



Disk Drive Interface — Disk storage systems and other peripherals are connected to computers through interfacing adapters such as the drive controller shown here. In this sketch, the controller is shown as a computer plug-in unit. In some computer systems, the controller is an integral part of the disk drive, and in some systems a disk drive interface is included on the computer's main printed circuit board. The flat ribbon interconnecting cable provides a bus for parallel data transfer and a bus for control signals. The cable is not a power conduit.

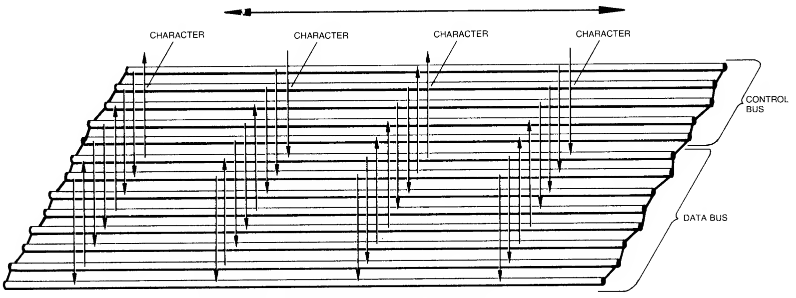
A disk drive controller is sometimes included as an integral part of the computer. More often, it is a separate module that plugs into a socket of the computer, or it is included as a subassembly of the disk drive unit. In any case, a drive controller provides the physical-electrical interface between the computer and disk drives, and includes several complex signal generating and processing functions.

In broad terms, a disk drive controller is responsible for two jobs: positioning the drive read-write head and getting data transferred between the computer and a storage disk. Head positioning of course is a vital function, but for understanding how disk storage works, more important are the functions involved in writing data onto a disk and reading data from a disk.

From memory to disk

Information that is to be saved from memory onto a disk is blocked up in the computer, and then each block is sent character by character to the drive controller. With only a few exceptions — Atari home computers come to mind — the characters are sent in a parallel byte-wide format. That is, all eight bits of each character "group" (only seven bits are used to represent the character itself) are transmitted simultaneously on an eight-conductor data bus.

Parallel Data Transmission — In computer information and data processing, characters are represented and manipulated as groups of elementary information units called bits. In the transmission of data, all bits of a character can be sent either simultaneously in parallel or serially one after another. Parallel transmission — illustrated here — is faster. A personal computer sends and receives disk files on an 8-bit parallel data bus at a rate of about 35,000 characters per second.



SECTION OF A MULTICONDUCTOR FLAT RIBBON CABLE

The Atari home computers communicate serially with their disk drives, sending or receiving character groups one bit at a time on a single conductor. Although the serial transmission rate may be as high as 2400 characters per second, this is still much slower than byte-wide transfers, and too slow for many business applications.

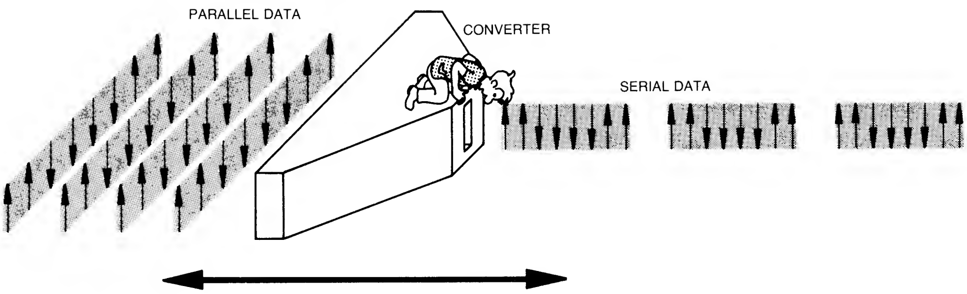
Data may be transferred to a disk either directly from computer memory or indirectly from memory through the computer central processor. The first method is referred to as direct memory access (DMA) and the second method as "programmed I/O." Programmed I/O, as the name suggests, depends on the repetitive execution of program instructions by the computer to perform the character-by-character transfer. DMA, which bypasses the processor data channel with a hardware data channel, is faster than programmed I/O. Most personal computer disk systems use programmed I/O for data transfers.

Data received by the controller is buffered and then formatted. A buffer is a kind of scratchpad, an area in random access memory (RAM) where data is temporarily stored — usually until the computer's central processor is ready to use the information. A controller's buffer RAM is usually large enough to hold as much information as can be stored on one disk sector. Buffering is relatively straightforward. Data formatting is more complex.

Data formatting begins in the computer. A file of information, a program, document, data base, etc., is sent to the drive controller a block of characters at a time, each block being sent only after the controller completes its storage operations and tells the computer to send another block. The maximum number of characters in a block is equal to the capacity of the controller buffer — which usually equals the storage capacity of a track sector. For personal computer diskettes, this now is almost universally 256 characters, but may be 128 characters or some other number. Fundamental characteristics of a drive determine the number of disk tracks, but sectoring of tracks is accomplished with a disk formatting program — assuming soft-sectoring of course. Disk formats and formatting are discussed in Section V.

The part the controller plays in data formatting is to demarcate the data blocks, and to append characters that provide for checking the integrity of the data and sector address during playback. The magnetic "marks" that separate one block from the next, signal the controller when it's time to stop writing to one sector and start writing to the next sector. In other words, these marks provide for incrementing the starting sector address, supplied by the computer, for each successive data block.

After formatting, the data is serialized. Serialization amounts to reorganizing the byte-wide "left-to-right" parallel bit arrangement of each character into a first-to-last serial arrangement. The conversion of character bit patterns back and forth between parallel and serial formats is a common computer operation.

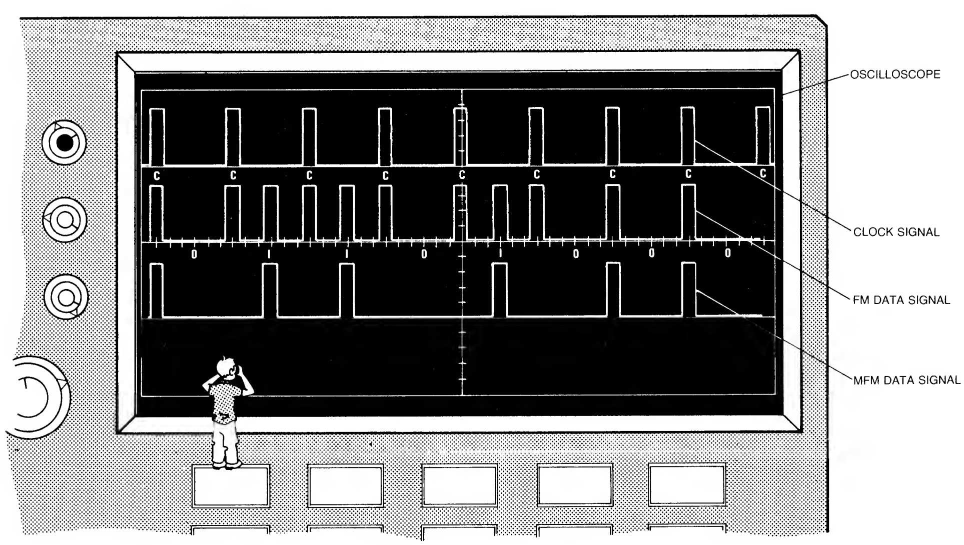


Data Conversion — A data format converter is in reality an integrated circuit (IC) chip. For parallel-to-serial conversion, all eight bits of a character (of a byte) are loaded into the converter at the same time, and then "clocked" out one bit at a time. For serial-to-parallel conversion, the bits are clocked into the converter one at a time, and then all eight bits are output simultaneously when signalled to do so. Notice that the bit sequence, 00111100, is not permuted by the conversion. Integrated circuits can convert character formats at a rate of several million per second.

Encoding, and character storage density

The next step in the sequence of disk write operations is called encoding. Encoding gives additional meaning to the character bits, which, physically, are electronic signal pulses. (A bit, recall, is a binary digit that may have only one of two discrete values. A bit may be represented physically by the presence or absence of a signal pulse, one or the other of two voltage levels, or some other measureable phenomenon.) A few years ago the disk drive controllers of personal computers encoded data signals in a scheme popularly known as single density. But current model personal computer disk storage systems use double-density encoding.

In single-density encoding, which is called frequency modulation or FM encoding by engineers, a clock pulse is paired with every data bit. An 8-bit character group is represented by (and stored as) eight clock pulses plus up to eight data pulses, depending on the number of 1's in the bit pattern. (A "clock is a very stable periodic signal, a nonstop train of precisely spaced pulses that serves as a timing reference for other signals.) In double-density encoding, '1' data bits are also stored as for FM encoding; however, only certain clock pulses are stored. The details of determining the clock pulses to be stored for each character are involved, but the net effect is to double the storage density and data transmission rate. In short, double-density encoding lets you store twice as much information in the same physical space required for single-density encoding, and access data twice as fast. Engineers call double-density encoding modified frequency modulation (MFM) encoding. Except for a few of the earliest units manufactured, all 5″ floppy drives are capable of double-density operation.

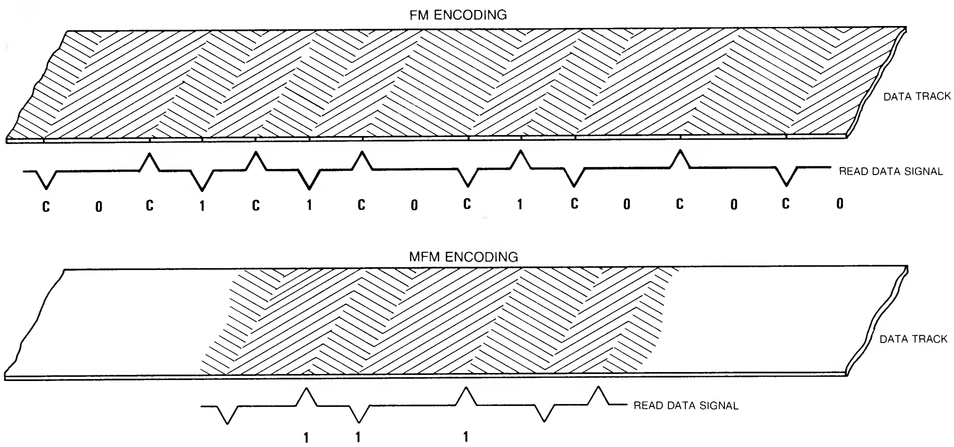


Single Density vs. Double Density Encoding — Information is FM encoded for single-density storage and MFM encoded for double-density storage. Shown here is the difference in the number of bits required to store the letter h in both codes. Notice that the MFM data signal has only about half of the pulses of the FM data signal. FM encoding requires that clock pulses be stored along with all data '1' bits. MFM encoding also stores all of the '1' bits of a character, but only a few clock pulses. The number of clock pulses that have to be stored depends on the character bit pattern. The rule is, "Write a clock pulse if neither the preceeding bit nor the following bit is a '1'." In this simulated oscilloscópic display, all three signal traces are on the same time base. The clock signal is shown only for reference; that is, the clock signal by itself is not stored.

For 5″ floppy disk drives, the single-density (FM) data transmission rate is 125,000 bits per second (15,625 characters per second) and the double-density (MFM) rate is 250,000 bits per second (31,250 cps). Most if not all rigid disk drives use double-density encoding. The data transmission rate of 5″ rigid disk drives is typically 5 million bits per second, or 20 times the rate of double-density 5″ floppies.

The rate that bits of information can be passed back and forth between the disk and the read-write head has a bearing on information throughput of the system, but head-disk data transfer rate is not the whole story. The actual time it takes to load a program or data from a disk into the computer's memory, or to save information in memory on a disk, is a complex operation limited by the other processes involved in saving and loading disk files — including the controller formatting and buffering functions described above — and most importantly, by the relatively modest speed of personal computer microprocessors. This is why the data throughput rate of a Winchester is not remarkably higher than that of a floppy even though the disk-head data transfer rate of a Winchester may be higher by a factor of 20 or more.

After encoding, the composite data-clock signal is amplified and supplied to the coil of the read-write magnet. Supplying pulses of energy to the magnet stores information on a disk by aligning elementary magnetic cells according to the encoding scheme. Thus, patterns of minute bipolar magnetic cells, encoded to represent each character of storage information, are formed on a disk track.



Single Density vs. Double Density Storage — Shown here is the difference between FM (single density) and MFM (double density) disk storage of the letter h. The two different shadings represent the two opposite alignments, N to S and S to N, of the microscopic magnetic track cells. A read pulse is generated each time a polarity transition (an intersection of cross-hatched zones) passes under the read-write head. Since, on the average, MFM encoding reduces by half the number of polarity transitions required per character, twice the number of characters can be stored in a given length of track. An FM character takes up about 0.004 inch of a diskette track, and an MFM character takes up about 0.002 inch.

From disk to memory

To read data, i.e., to retrieve previously recorded information, the write sequence is reversed:

- A read-write head is selected and positioned over a particular track or cylinder. For a floppy drive, the head is loaded if necessary.
- The signal pulses picked up by the read-write head are amplified and converted from ill-defined analog signals into unambiguous digital pulses, the signal waveforms a computer understands.
- The data pulses are separated from the clock pulses. This is one of the more exacting functions.
- The sector address is evaluated, and if it matches the address the computer is looking for, the processing continues; otherwise, the data is ignored. Sector addresses are stored during disk formatting as explained in Section V.
- The data is checked to see if it is still exactly the same as originally stored. If it is not, the data is read again. This step is usually repeated several times to determine if the problem is a "soft" error (a transient error caused, for example, by a dust particle) or a "hard" error. Soft errors usually clear up; hard errors do not and are reported to the operator as read errors.
- The data bit stream is deserialized by reformatting the character bits into the byte-wide information units compatible with the computer's eight-conductor data bus.
- The address and error-checking fields are discarded in what amounts to a "deformatting" operation.

- The data, now stripped of the "housekeeping" fields, is buffered, and then transferred to the computer. The transfer is made either by DMA or programmed I/O.

The circuits required to perform disk read-write functions now are mostly included on the drive controller. However, since semiconductor manufacturers are continuing to combine more and more of these functions into integrated circuit chips, it's possible — even likely — that in the future all controller functions will be implemented on the integral drive electronics circuit board.

A little sorcery, too

Although the different functions of disk I/O operations are readily described, controller design is still a blend of art and science, and not all that straightforward. The data separation function, for example, is a source of problems that has plagued some floppy disk drive systems. Information is sent to the drive read-write head at a constant rate independent of which track the head is over, and consequently the elementary storage cells are packed closer together on the shorter sectors of a disk's inner data tracks. Depending on how adjacent cells are aligned, some will pull together and some will push apart, just like large magnets. What results is a phenomenon known as "bit shifting" in which the cells are skewed from their nominal positions and give the effect of skittering around during playback. Bit shifting, which can be partly compensated for by modulating the read-write head current during write operations, introduces a "moving-target" complexity to the data-clock separation function that can't be performed reliably with simple data separator designs — especially for double-density storage. Unreliable clock-data separation is probably the major cause of disk read errors that are traceable to inept design.

Software: The disk operating system 5

Disk systems for personal computers come with a disk operating system or DOS. Although a DOS includes routines (short programs) to operate a disk storage system, it is not, as the name seems to suggest, a program limited to providing for operation of a disk system. Rather, a DOS is a *disk-based* computer operating system. A computer operating system (OS), whether disk based or not, serves as an intermediary between a user's application programs and the machine itself, passing on instructions and getting maximum performance out of all available system resources. Besides quarterbacking the computer's operation, a personal computer DOS also provides the operator with a set of utilitarian programs and a high-level, disk-accessing programming language such as Basic. A personal computer DOS may be as small as 1,000 bytes (characters) or as large as 32,000 bytes — or even larger with all bells and whistles. Of course a primitive DOS does not provide the features of a large DOS. In this Section, we'll take a look at those components of a "disk-based operating system" that particularly concern disk operations.

Only two programs, a routine to write information from computer memory onto a disk and a routine to read information from a disk into memory, are essential for disk storage. But a DOS usually includes a number of other disk programs which, if not absolutely necessary, certainly make life a lot easier for the operator.

Some DOS routines interact with the user, and some are inaccessible and invisible, doing their job without intervention and with little or no awareness by the operator. A visible and often-used program is one called BACKUP, a selection from the DOS menu of auxillary programs, that copies one disk — blank spaces and all — onto another disk.

Invisible to the user, at least to the non-programming user, is the file manager. A file manager is a set of routines that application programs use in manipulating files. A file manager raises the level of operator involvement to where he or she can save and load files without getting bogged down in tedious "housekeeping" details.

A file is a continuum of related information records. Both programs and data are stored as a chain of records, and either is sometimes referred to idiomatically as a "file." Programmers think of a file both as a physical structure and as a logical concept. A physical file is maintained on the device itself; a logical file is a software concept. File records also may be physical or logical. Programmers work with logical records, which, generally speaking, do not fit neatly into a disk's physical record space, a problem that is resolved by the file manager.

Two sets of DOS routines are used by application programs to move files between a computer and its disk storage device: the routines of the file manager, or file management system (FMS), and a set of routines called a disk driver. Besides the disk driver, a DOS also includes other device drivers, such as one for sending characters to a printer (a printer driver) and one for receiving characters from the data terminal keyboard (a keyboard driver). Usually device drivers are resident in memory and therefore immediately accessible to calling programs.

A sophisticated file manager performs many tasks. One such task is to allocate disk storage space and see to it that files are stored and retrieved intact. It does this by generating and maintaining a disk-resident file, called a directory, which it automatically updates as files are added or deleted from a disk. Some file managers are able to separate a file into parts and store the parts in any available free sectors, regardless of whether or not the sectors are consecutive. This space-efficient method of file storage is called "dynamic" file allocation. A less sophisticated file manager stores files in the "next" available space, and a primitive DOS may even leave file allocation up to the user who must type and enter the starting sector number for each file, and maintain a written log of the numbers of the first and last sectors of all files on a disk. On 5″ floppies, at least one full track is reserved exclusively for the disk's file directory.

A file manager resolves differences between the variable logical record lengths of applications and the constant record length — essentially the capacity of one

track sector — of the disk storage system. If, for example, the records of an application were 64 characters long — say the names and addresses of a mailing list — and the track sectors held 256 characters, the file manager would assemble the logical records into physical storage records, all the while keeping track of what's stored where, as it must do for disassembly during playback.

An advanced file manager also provides for amenities such as the ability to manipulate files by name instead of by a storage address number, the ability to protect against writing over individual files, and the ability to make selected files inaccessible except to users with a password.

The DOS file manager communicates with the DOS disk driver, calling on driver routines whenever it needs to input or output the physical records of a file. Higher level programs, the file manager in this case, usually "call" low-level routines to perform the final device communication function — just as application programs call file manager routines to handle detail file operations. Sets of routines, such as those of a file manager or a device driver, are usually spoken of by programmers as "modules."

The command *is* the program

A DOS also includes what we'll call disk service programs, a library of disk-related programs which a user can run (put to work) by entering a word at the keyboard. These programs are commonly referred to as "commands," as in this example of computerese:

MACDOS has two types of commands, built-in and transient.

What is meant by this statement is that the disk operating system named MACDOS includes two types of user-accessible programs, built-in and transient. What's meant by "built-in" and "transient" we'll get to in a moment. An operator can run one of these programs by typing and entering the program keyword, i.e., the command word. We'll also speak of this class of programs as "commands" because it's standard, unavoidable computer prose.

Although called a disk operating system, implying that the set of programs and routines that comprise the DOS are disk based, in fact most personal computer disk operating systems are partly memory resident and partly disk resident. In the above example of computerese, "built-in" means the commands are memory resident and "transient" means the commands are disk resident. Disk-resident commands, unlike the commands in memory, must be loaded into computer memory before they can be run. Disk operating systems generally include both types of commands.

Representative of built-in commands of personal computer disk operating systems is one usually abbreviated as DIR (for directory) or CAT (for catalog). This command accesses a disk directory file and displays directory information about all other files on the disk.

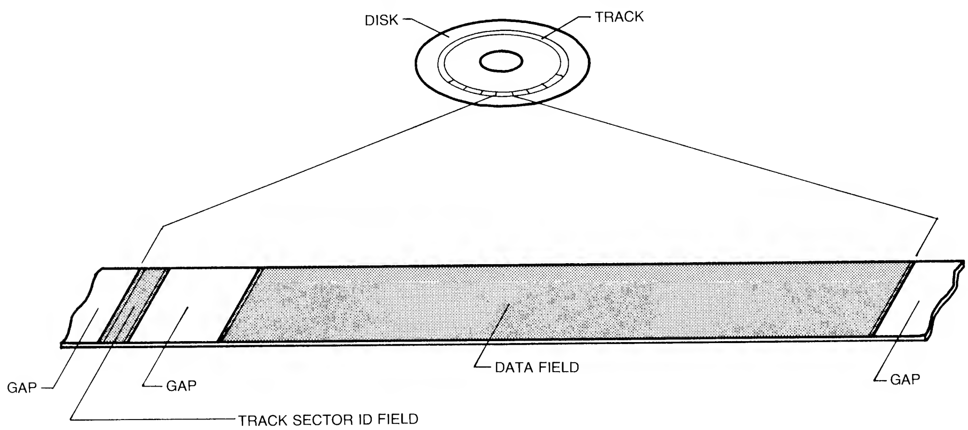
The FORMAT command, which prepares a blank disk for sector-organized recording and sets up the disk directory, is usually disk resident. Disk-resident commands are often called "utility commands" or simply "utilities." Some personal computer disk operating systems accommodate extension of their basic DOS library of disk-resident commands with user-written utilities.

A file cannot be recorded on an unformatted disk, which is the way diskettes are sold, so FORMAT is an essential utility for floppy systems. Although the disk (or disks) of a Winchester drive is formatted before the drive leaves the factory, a hard disk FORMAT utility still may be needed at the installation site to write an "empty" disk directory file, or to reformat a disk that comes with a format which is incompatible with the host drive controller.

Disk track formats

A FORMAT utility generates sectored tracks, and gives each sector of every track a unique identification. A sector has two main fields of characters. The first field is used to identify the sector, and the second field is the user data field. The two fields and the sectors themselves are separated by gaps of "null" characters. Track sectors can be set up to store 128, 256, 512 or more user file characters. The tracks of a 5″ Winchester are typically formatted into 32 sectors with each sector storing 256 user characters. A single-density 5″ floppy usually has 10 sectors and a double-density floppy 18 sectors. Why not 20 sectors per track for the double-density disk? Because the "gaps" between sectors are necessarily larger for double-density storage than for single density. A 40-track single-density diskette can store 99,840 user characters, assuming one track is

used for the directory (256 characters per sector × 10 sectors per track times 39 tracks), and a double-density 40-track diskette can store 179,712 user characters (256 characters per sector × 18 sectors per track × 39 tracks per disk).



TYPICAL SECTOR

Soft-Sector Track Formats — Formatting organizes disk tracks into numbered sectors. A track sector consists of two main fields of characters, a sector ID field and a data field. The ID field is separated from the data field by a "gap." The sectors themselves also are separated by gaps. Gaps actually are 16 or more bytes of what can be thought of as "null" characters. Both single-density and double-density formats have the same general layout, differing mainly in the number of characters that make up the gaps — the number being about twice as great for double-density. Each of the two main fields begins with a subfield that serves to flag the beginning of the field. And each of the main fields ends with two special error-checking characters. The error-checking characters, which are derived from the information in the fields, provide a way to verify that the data read is the same as the data that was stored. Between these two subfields is the crucial information: sector location, size and identification bytes in the sector ID field, and the file characters in the data field. The standard IBM single- and double-density soft-sector formats store 128 and 256 user characters, respectively, in the main data field.

In passing it should be mentioned that a FORMAT utility does not give track sectors consecutive addresses. Instead, addresses are assigned (and recorded) in a way that "interleaves" sectors. Consequently, more than one rotation of the disk is required to access all sectors of a track. Sector interleaving is necessary because drive controllers do not process information fast enough to allow the disk read-write head to access consecutive sectors.

Hard disk drive controllers include a hardware circuit function that automatically formats a track when commanded to do so. Most floppy drive controllers, on the other hand, layout the track format in memory and then transmit the format to the drive controller, which writes it on the disk.

There are no industry-wide format standards for soft-sectored 5″ floppy disks; however, two IBM-developed 8″ disk formats, the 3740 single-density format and the System 34 double-density format, are, in modified form, personal computer defacto standards.

Getting it together

We'll conclude this Section by describing the operations involved in saving data in memory on a disk. Specifically, we'll store a text file named MSCRIPT, which we've written and edited with a word processor program and have in memory, on a formatted diskette in the #2 drive of our multi-drive floppy disk storage system. We'll assume our DOS transfers files by programmed I/O (Sec. IV).

The word processor we're using initiates a file storage operation when the letter S (for save) is entered at the computer keyboard. A word processor typically has a text entry-edit mode, and a command mode, so we'll be in the command mode when we enter the 'S'. Otherwise, the word processor would treat the 'S' as an ordinary text character.

The word processor will call the DOS keyboard driver, the keyboard input-character routine, to bring the 'S' into the computer. The 'S' command will be passed to a module of the word processor that we'll call a command processor. The DOS also has a command processor module, but it won't be used in this application. The word processor command module recognizes 'S' as the name of its Save Text routine, and passes control of the computer to this program. The Save Text program executes automatically, beginning with the issuance of prompts to the operator for the name of the file to be saved and other particulars. For example, the Save Text routine might display:

NAME OF FILE?

to which the operator would respond by typing and entering MSCRIPT. Then the Save Text routine might prompt with

DRIVE NO?

to which the operator would respond by typing and entering the numeral 2.

When the operator responds to the last prompt, his inputs, MSCRIPT and the numeral 2 in this case, are passed to the DOS file manager. Being memory resident, the file manager goes right to work, querying the disk file directory (to see if MSCRIPT is a new file or existing file), locating a starting sector, assembling physical records from the characters pouring in one by one from the word processor, and moving the records from memory to the controller. After the file is stored, the file manager will update the on-disk file directory and return system control to the word processor program.

The file manager calls routines of the disk driver to communicate with the drive — or, more precisely, with the drive controller. Each time the file manager is ready to move a record to the controller, that is, each time the controller signals the file manager it is ready to receive a record, the file manager calls the disk driver write-sector routine, and the write-sector routine transmits the record to the controller buffer.

The next step is to get the information (the record) off the controller and onto the disk. Disk drive controllers respond to one-character commands, that is, to single, 8-bit bytes. A sophisticated drive controller can perform all of its functions in response to only a few commands, and, in general, the more sophisticated the design, the lighter is the demand on the services of the host computer processor. Drive controller commands are given names that described the command functions, such as Format and Cal (for calibrate).

How does the drive controller respond to a command? It responds to a command — "executes" a command — by testing and manipulating selected drive control signals in a predetermined sequence that's built right into the controller circuitry. Suppose the disk driver write-sector routine sends a head-positioning Seek command to the controller. The controller would respond as follows. First it would establish that it is busy and not receptive to other commands. Then it would fix the read-write head step rate, set up the direction of head movement and step the head to the desired track (or cylinder for a hard disk drive).

Once the read-write head settles over the right track, a Write command is issued by the computer. The controller executes the Write command about the same as it executes the Seek command. First it signals that it's busy. Then it loads the head (if necessary), searches for the right sector address, and writes the data onto the disk.

The final responsibility of the Write function is to change the sector address register to the address for the next record. All of the records of a file are written to disk in this way, one after another, until the entire file is saved.

To summarize, we've "walked through" the steps involved in saving text in memory as a disk file. We've traced a path through several "layers" of software, starting with the word-processing application program and ending with the disk driver module. The path we've followed is typical of the way a computer processes a device I/O operation initiated by the user. Naturally we've cut some corners. For example, we didn't mention the important function of detecting and handling write errors: How do you check to confirm that the logical record is stored without error? And how do you handle these discrepancies when they occur? Nor have we said anything about initialization of the controller, a procedure that provides an essential reference point for the commands to follow. Nevertheles, we've presented a foundation and a little framework upon which to build a better understanding of how personal computer disk operating systems work.

The Percom Data legacy

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So now you know what you need to know to help make your relationship with your disk stoarge system more than just "meaningful." This booklet doesn't have all the answers to all your questions . . . because if you're serious about computing, no one can answer all your questions in one short book. In fact, knowing what we know about computer design and manufacture, anyone who tells you they have all the answers has to have only one oar in the water. Percom Data knows this peripheral business. And we know that our contribution over the years has helped to make a tad more sense out of the sometimes conflicting and confusing technology.

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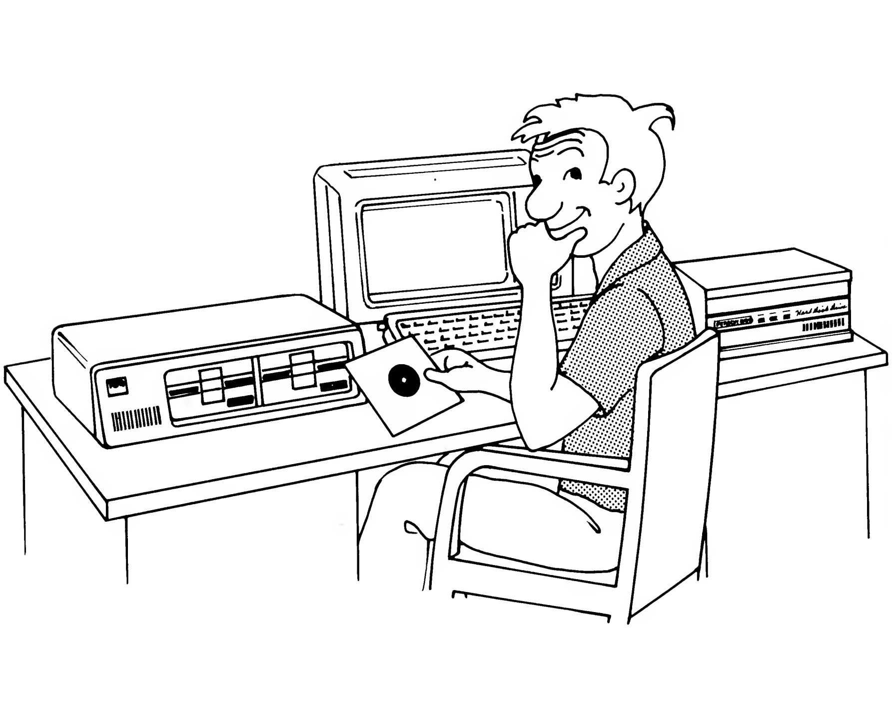

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